BROOKHAVEN NATIONAL LABORATORY
LASER CONTROLLED AREA
STANDARD OPERATING PROCEDURE (SOP)

This document defines the safety management program for the laser system listed below. All American National Standard Institute (ANSI) Hazard Class 3b and 4 laser systems must be documented, reviewed, and approved through use of this form. Each system must be reviewed annually.

System description: Class IV Nd:YAG laser, operated at 3rd harmonic (λ=355 nm) Max pulse energy = 11 mJ, max repetition rate = 10 Hz
Location: West end of Bldg 1006 (STAR Wide Angle Hall), south of DX magnet in RHIC tunnel

LINE MANAGEMENT RESPONSIBILITIES

The Owner/Operator for this laser is listed below. The Owner/Operator is the Line Manager of the system and must ensure that work with this laser conforms to the guidance outlined in this form.

Owner/Operator:		
Name: Scott W. Wissink	*Signature:* ***Signature on File***	*Date:*

AUTHORIZATION

Work with all ANSI Class 3b and 4 laser systems must be planned and documented with this form. Laser system operators must understand and conform to the guidelines contained in this document. This form must be completed, reviewed, and approved before laser operations begin. The following signatures are required.

C. Weilandics	***Signature on File***	
BNL LSO printed name	*Signature*	*Date*
Asher Etkin	***Signature on File***	
C-A Department ES&H Approval printed name	*Signature*	*Date*

APPLICABLE LASER OPERATIONS
X Operation X Maintenance Service X Specific Operation X Fiber Optics

LASER SYSTEM HAZARD ANALYSIS

Hazard analysis requires information about the laser system characteristics and the configuration of the beam distribution system. The analysis includes both laser (light) and non-laser hazards. A Nominal Hazard Zone (NHZ) analysis must be completed to aid in the identification of appropriate controls.

LASER SYSTEM CHARACTERISTICS					
Laser Type *(Argon, CO_2, etc.)*	Wavelengths	ANSI Class	Maximum Power or Energy/Pulse	Pulse Length	Repetition Rate
Nd:YAG	355 nm (1064 and 532 nm internal to laser head)	IV	11 mJ / pulse @ 355 nm	4-6 ns	10 Hz max

☐ **Cryogen Use**

Describe type, quantity, and use.

None

☐ **Chemicals & Compressed Gasses**

Describe type, quantity, and use.

None

☒ **Electrical Hazards**

Description *(Describe the power supply to the system).*

The power supply (external to the lasing head) is supplied by the manufacturer, and is rated at 120 VAC, 60 Hz, 250 watts. Potentially lethal voltage levels exist inside the power supply.

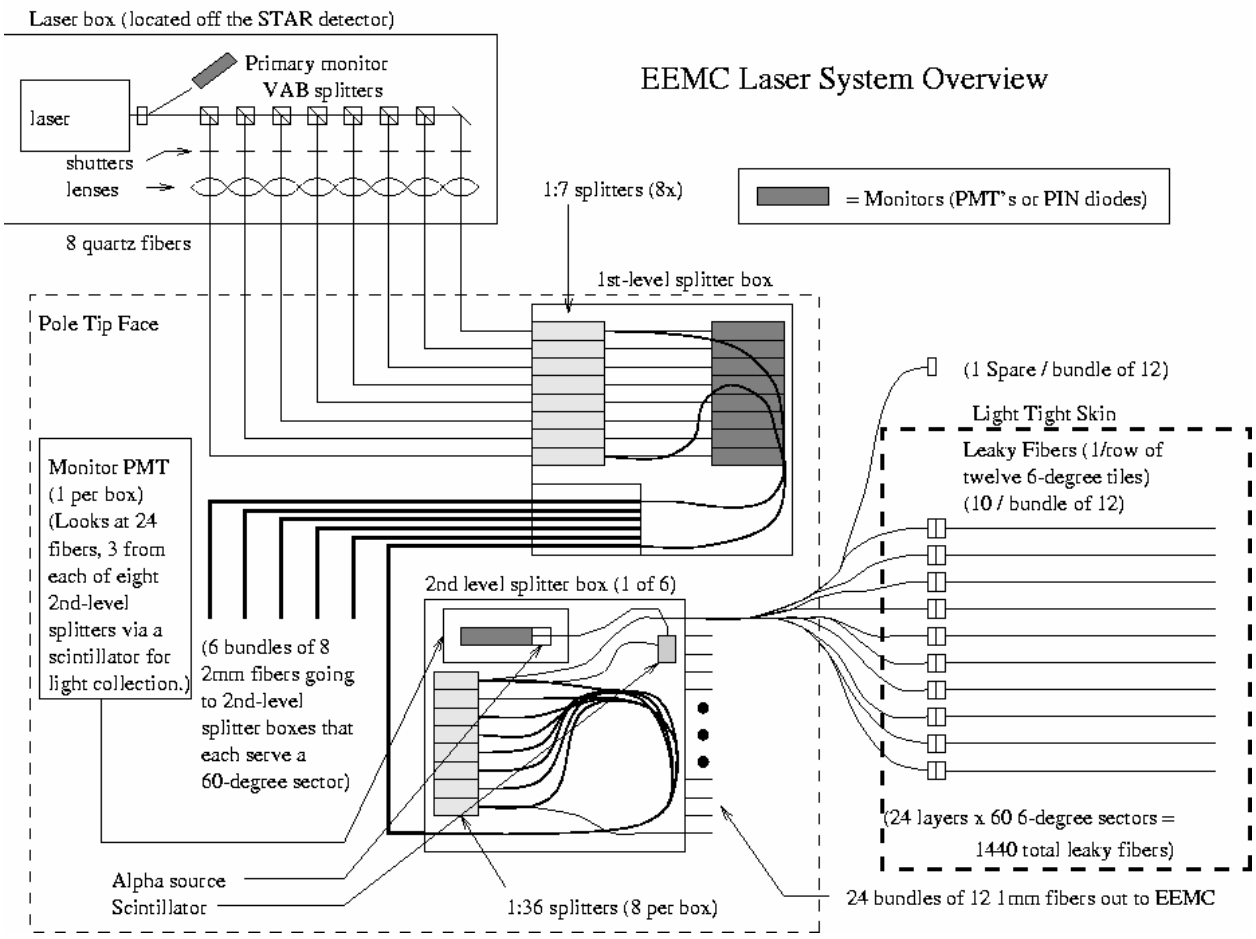
☒ **Other Special Equipment**

Description *(Equipment used with the laser[s]).*

The laser head itself contains the actual Nd:YAG lasing rod, a remotely controlled optical attenuator (1/2-wave plate followed by a cubic beam splitter), the 2nd and 3rd harmonic

generators, and two 90° totally reflecting mirrors. The laser head is mounted on a 2′x5′ commercial optical bench inside an interlocked aluminum box. This box also contains a single 90° mirror, a diffraction grating, a PMT and resistive base, seven partially reflecting mirrors, eight focusing lenses, eight neutral density filters, and eight 2-m lengths of high-damage threshold quartz optical fiber. Light exits the box via eight SMA bulkhead connectors, then passes through eight 21-m lengths of quartz fiber to the 1st-level splitter box. This box contains a single block of Spectralon and eight PIN diodes and preamplifier electronics, plus connectors for the six bundles of 2-mm plastic fiber that pass light to the six 2nd-level splitter boxes. Each of these boxes contains a block of Spectralon for the splitting cavities, a single PMT and base, and many connectors for the 1-mm fibers that carry light to the individual EEMC megatiles.

A schematic overview of the system configuration illustrating the role of much of this equipment is provided below. This is explained in more detail in the following section of this document.



Laser System Configuration: Describe the system controls *(keys, switch panels, computer controls),* beam path, and optics *(provide a functional/block diagram for complicated beam paths)*.

Laser operation is keyed (key is removable from power supply). All controls are provided via an RS-232 cable from either the manufacturer-supplied control panel or a local PC with ethernet

connection. The setting of the optical attenuator, the flashlamp high voltage, and the laser firing repetition rate are controlled over this cable, as well as starting and stopping (or pausing) the laser from firing. The only 'beam path' is within the primary aluminum box; outside of this box, the laser light is always fully contained within either splitting cavities or optical fibers. The schematic on the previous page may be useful while reading the following description of the configuration for the STAR EEMC (**E**ndcap **E**lectro**M**agnetic **C**alorimeter) laser system.

The laser system includes components located in the RHIC tunnel just west of the STAR WAH, on the back of the west poletip of the STAR magnet, and within the EEMC itself (which is mounted on the front of the same poletip). The UV laser resides inside an interlocked (and lockable) aluminum box, on a table in the RHIC tunnel, just south of the DX magnet. A series of seven partially reflecting mirrors, mounted on an optical table within this box, are used to form eight beams of roughly comparable intensity (I_{max} = 1.3 mJ[1]), each of which is focused down into 600-μm diameter single strand silica core optical fibers. These 8 fibers transport the UV light to the back of the poletip and into a single "1st-level splitter box," located near the top of the magnet. Within this light-tight box, the light from each fiber emerges into a diffuse reflective cavity, and a fraction of the light (~5%[1]) is captured by seven 2-mm diameter plastic optical fibers, chosen for their excellent transmission (low attenuation) in the UV. Bundles of eight 2-mm fibers then carry the light to six "2nd-level splitter boxes," distributed around the outer edges of the back of the west poletip. Inside these boxes, the light from each fiber is distributed among a large number (36) of high-transmission 1-mm fibers, using a second type of diffuse reflective cavity. Each of the resulting 1440 1-mm fibers then transports a very small fraction (~$1:10^6$) of the initial UV light around to the front of the poletip and into a special `leaky' fiber that is embedded within every EEMC megatile. As the laser light propagates through this fiber, a set of precision scribes made along the fiber surface injects a small pulse of UV light into each of the 12 individual tiles. The laser energy, level of splitting, and 'leak' sizes have been chosen so that each EEMC tower PMT can "see" a light pulse comparable in intensity to that produced by the shower of a 150 GeV electron, while an attenuator internal to the laser head (and remotely adjustable) will allow us to simulate the light response of a minimum-ionizing particle as well.

Associated with each of the three levels of splitting are different types of monitoring. Inside the primary box, a single PMT views ~1% of the laser output light (through a neutral density filter), which is deflected from the main beam using a special diffraction grating. After the first splitting on the poletip, one of the seven 2-mm fibers from each cavity injects its light onto the face of a photodiode. Information from the PMT and the PIN diodes will be used to monitor the actual output intensity and the relative intensities of the 8 beams from the primary box. Finally, each of the six 2nd-level splitter boxes contains a single PMT, which provides event-by-event normalizations for each laser pulse seen by the towers within that 60° sector.

DEVELOP CONTROLS
IDENTIFY ES&H STANDARDS

Recognition, evaluation, and control of laser hazards are governed by the following documents.

[1] All values based on detailed attenuation and splitting efficiencies calculations, verified by measurements at IUCF.

American National Standards Institute (ANSI) Standard for Safe Use of Lasers;
(ANSI Z136.1-2000)

Laser Safety Subject Area

Brookhaven National Laboratory Environment Safety and Health Standard: 1.5.3 INTERLOCK SAFETY FOR PROTECTION OF PERSONNEL

ENGINEERING CONTROLS

☒ Beam Enclosures	☒ Protective Housing Interlocks	☐ Other
☒ Beam Stop or Attenuator	☒ Key Controls	
☒ Activation Warning System	☒ Other Interlocks	
☐ Ventilation	☒ Emission Delay	

Describe each of the controls in the space provided below this text. Interlocks and alarm systems must have a design review and must be operationally tested every six months. Controls incorporated by the laser manufacturer may be referenced in the manuals for these devices. **If any of the controls utilized in this installation requires a design review, a copy of the design review documentation and written testing protocol must be on file. Completed interlock testing checklists should be retained to document the testing history.**

Engineering Controls Description:

1. Beam enclosures: the laser beam is always fully contained within Spectralon splitting cavities or inside optical fiber, except for the initial splitting inside the primary box. This box is light-tight and interlocked to kill laser power if opened.

2. Beam stop or attenuator: The laser head contains a manual shutter at the exit aperture that can stop the beam. The beam(s) to individual quartz fibers can be temporarily blocked with thin pieces of Spectralon. The only attenuation of the beam occurs in the commercial optical attenuator located inside the lasing head, or in a few high-damage threshold neutral density filters located in front of several of the monitor detectors.

3. Activation warning system: When the laser is operating with the lid to the primary box open, a warning light indicating that UV light is present will be posted at the access to the area enclosure (at the top of the ladder needed to reach the laser area).

4. Protective housing interlocks: The actual laser head is enclosed in a protective housing (provided by the vendor) that prevents access to radiation in excess of Class I limits, except for the output beam. This housing is light-tight and interlocked to kill laser power if opened (see item 6. below). Laser operation is interrupted if the laser head cover is removed. The laser power supply, which contains high voltages, is also powered down if its cover plate is removed.

5. Key controls: The power supply cannot be energized unless a removable key is in place and turned. During extended periods of access to the STAR Wide Angle Hall, this key will be locked in a cabinet in the STAR trailer.

6. Other vendor-supplied interlocks: The manufacturer has installed interlocks such that laser operation will be interrupted if:
   - The laser head cover is removed (item 4. above)
   - The control cable (RS-232) is detached from the power supply
   - The laser head umbilical cable is detached
   - Cooling water temperature is too high or too low
   - Remote interlock is not satisfied (see immediately below)

7. User-supplied interlocks: The IUCF group has installed interlocks to ensure that laser operation will be interrupted if:

   - The primary box lid is opened
   - Anyone attempts to enter the laser area. This is implemented using an infra-red sensor which has been mounted directly outside the enclosure curtain.

8. Emission delay: When the laser system is first turned on, or after it has been interrupted by an interlock not being satisfied, a restart involves two steps – pressing a START/STANDBY button, which sounds an audible alarm (beep) for seven seconds, followed by pressing the FIRE LASER button. Thus, after an interrupt, the laser can not be re-fired for at least seven seconds. The actual delay is somewhat longer, because the START/STANDBY button can only be energized if the flashlamp voltage has been run to zero. Thus, to restart laser firing:

   - Run flashlamp voltage to zero
   - Push START/STANDBY button
   - Wait 7 seconds
   - Push FIRE LASER button
   - Set flashlamp voltage to desired value

   If a PC is used, rather than the control panel, a series of RS-232 commands are issued instead of pushing buttons, but the above sequence (including the delay) must still be followed.

9. Other: an enclosure curtain, made of material opaque in the near UV, optically isolates the primary box area from the STAR WAH. Access to the enclosure is physically limited to a single entrance.

See OPM 8.4~ CA-100_-_ Interlock Test Checklist

ADMINISTRATIVE CONTROLS

☒ Laser Controlled Area ☒ Signs ☒ Labels ☐ Operating Limits

The format and wording of laser signs and labels are mandated by BNL and ANSI standards. Only the standard signs are acceptable. Standard signs are available from the BNL Laser Safety Officer.

All lasers must have a standard label indicating the system's wavelength, power, and ANSI hazard class. Required labels must remain legible and attached. The manufacturer should label commercial systems.

Standard Operating Procedures (SOPs) are required for laser system operation, maintenance (including alignment), and servicing. The SOPs need only contain the information necessary to perform these tasks and identify appropriate control measures including postings and personal protective equipment. The BNL Laser Safety Officer must approve SOPs and copies should be available at the laser installation for reference and field verification of stated control measures.

Administrative Controls Description:

Laser Controlled Area: The laser is normally operated fully enclosed (Class 1). If it becomes necessary to perform maintenance or service on the laser and associated optics, a temporary laser controlled area will be established in the laser enclosure.

Signs: Appropriate laser signs are posted at the entrance to the laser area.

***Labels**: Appropriate warning labels are posted on the cover of the laser and splitters. Additional labels have been attached to the quartz fibers that extend from the primary box to the 1st-level splitter box.*

Sets of operating procedures and associated checklists have been developed for routine operation and special operations, as well as for verification of the laser interlock system. Prior to performing any special operations, the Laser Interlock System checklist must also be complete.

See OPM 8.4 Att. CA-100_-_ Guidance for Alignment/Maintenance Operations
See OPM 8.4 Att. CA-100_-_ Guidance for Normal Operations

CONFIGURATION CONTROL

A checklist must be developed for the purpose of verifying the placement and/or status of components that are used to mitigate hazards by configuration control. Examples include any protective housings, beam stops, beam enclosures, and any critical optics *(mirrors or lenses that could misdirect the beam and result in personnel hazard)*. Entries should also be included to ensure placement of required signs and labels and status of interlock verification. Completed checklists must be posted at the laser location. The checklist does not have to be redone unless there has been a system modification, extended shutdown, or change of operations.
C-AD OPM

PERSONAL PROTECTIVE EQUIPMENT

☐ Skin Protection ☒ Eye Wear

Skin Protection: For UV lasers or lasers that may generate incidental UV in excess of maximum permissible exposure (MPE) describe the nature of the hazard and the steps that will be taken to protect against the hazard.

Eye Wear: All laser protective eyewear must be clearly labeled with the optical density and wavelength for which protection is afforded. Eyewear should be stored in a designated sanitary location. Color - coding or other distinctive identification of laser protective eyewear is recommended in multi-laser environments. Eyewear must be routinely checked for cleanliness and lens surface damage.

1. For invisible beams, eye protection against the full beam must be worn at all times unless the beam is fully enclosed.
2. For visible beams, eye protection against the full beam must be worn at all times during gross beam alignment.
3. Where hazardous diffuse reflections are possible, eye protection with an adequate Optical Density for diffuse reflections must be worn within the nominal hazard zone at all times.
4. If you need to operate the laser without wearing eye protection against all wavelengths present, explain the precautions that will be taken to prevent eye injury.

_____

Define eyewear optical density requirements by calculation or manufacturer reference and list other factors considered for eyewear selection. The BNL Laser Safety Officer will assist with any required calculations.

EYE WEAR REQUIREMENTS					
Laser System Hazard	Wavelength (nm)	Calculated Intra-beam Optical Density	Diffuse Optical Density*	NHZ** (meters)	Appropriate Eye Wear***
Nd:YAG(laser head)	355 nm	4.5 OD(10 sec.) 2.5(1% pwr.)	1 OD (600 sec.) NA(1% pwr)	0.7 meters NA	Nd:YAG(laser head)
Laser box(fiber)	355 nm	3.6 OD(10sec.) 1.6(1% pwr.)	0.15 OD (600 sec.) NA	0.24 meters NA	Laser box(fiber)
1st level splitter(bundle) output	355 nm	3.6 OD(10sec.) 1.6(1% pwr.)	0.2 OD (600 sec.) NA	0.25 meters	1st level splitter(bundle) output

* Diffuse ODs are calculated assuming a 600 second exposure, a viewing distance of 20 cm, perfect reflectivity, and viewing normal to the surface. The ODs required can decrease for more typical conditions in the laboratory.

**The Nominal Hazard Zone is that zone or distance inside which exists a hazard to the eye from a diffuse reflection (as well as direct or specularly reflected light) for the time specified, in this case, 600 seconds (10 minutes).

***Specified eyewear may not be the only possible option, but represents an approved choice; depending on other laser hazards present in the lab, other eyewear may be acceptable provided the optical densities are equivalent or greater than those required.

EYE WEAR SPECIFICATIONS		
Laser System Eyewear Identification	Wavelengths	Optical Density
Elvex LG-0601/18	180 – 380 nm 10,600 nm	6 5

Nominal Ocular Hazard Distances Calculations

Because the beam emanating from the optical fibers typically has a fairly high divergence, Nominal Ocular Hazard Distance(NOHD) calculations have been supplied. The NOHD is the distance, beyond which viewing the direct beam, for the time specified(in this case 10 seconds)

ceases to become a hazard. Where the viewing distance approaches or extends beyond a "standard" viewing distance of 20 cm(or, about 8 inches) the NOHDs have been printed in bold type.

Conservative assumptions have been made with respect to the calculations, namely, the following apply:
Laser head output: 11mJ per pulse, beam divergence negligible
Laser box fiber output: 1.4mJ per pulse(each fiber).
First level splitter bundle output: 1.6mJ per pulse(per bundle of 8).
Divergence: example full angle divergences of 10 degrees and 20 degrees were applied. It was felt that these would be typical if not conservative estimates of the spread of the beam.
Fiber transmission loss: no internal or junction fiber losses are assumed.
Pulse Repetition Frequency(PRF): the maximum PRF of 10 Hz was used
Maximum Permissible Exposure: the conservative thermal ($0.56t^{0.25}$)limit was applied, where t is the pulse length(4ns); hence the resultant single pulse MPE is 4.5mJ/cm^2.

Nominal Ocular Hazard Distances Calculations

Output	Divergence	10 sec. NOHD
Laser Head (full power) 11mJ/pls	10 degrees (0.175 radians)	**98.6cm**
	20 degrees (0.350 radians)	**49.3cm**
Laser Head (1% power) 0.01mJ/pls	10 degrees (0.175 radians)	9.8cm
	20 degrees (0.350 radians)	4.9cm
Laser Box (full power) 1.4mJ/pls/fiber	10 degrees (0.175 radians)	**35.2cm**
	20 degrees (0.350 radians)	**17.6cm**
Laser Box (1% power) 14μJ/pls/fiber	10 degrees (0.175 radians)	3.47cm
	20 degrees (0.350 radians)	1.73cm
1st level splitter output	10 degrees (0.175 radians)	**37.3cm**

(full power) 1.6mJ/pls/bundle	20 degrees (0.350 radians)	**18.6cm**
1st level splitter output (1% power) 16μJ/pls/bundle	10 degrees (0.175 radians)	3.7cm
	20 degrees (0.350 radians)	1.8cm

TRAINING

LASER SAFETY TRAINING

Laser Operators must complete sufficient training to assure that they can identify and control the risks presented by the laser systems they use. Owners/Operators and Qualified Laser Operators must complete the awareness level BNL World Wide Web based training course (TQ-LASER) every two years.

Qualified Laser Operators must also complete system-specific orientation with the system owner/operator. **System-specific training must be documented with a checklist that includes**

- Trainee name and signature
- Owner/Operator signature
- Date
- Brief list of topics covered e.g.
  - Review of SOPs;
  - Review of working procedures, and other program specific documentation.

All laser safety training must be repeated every two years.

See BTMS

Procedure checklist for alignment and maintenance

of the EEMC Laser

(Only authorized and properly trained laser operators[*] listed in the SBMS Laser Controlled Area SOP

may perform these steps. The lid of the primary box may be open.)

- Sign out the laser power supply key from the cabinet in the STAR trailer.
- Check that the removable access ladder is in place and available.
- Inspect primary, 1st-, and 2nd-level splitter boxes to ensure that no interconnecting fibers have been disconnected or removed.
- Verify the integrity of the enclosure curtain.
- Ensure that only authorized operator are within the curtained enclosure.
- Verify that operation of the primary box lid interlock: follow procedures and complete appropriate section of the "Laser Interlock Checklist.".
- Set up laser warning sign at top of ladder and lighted sign at the access point.
- Check that the infra-red beam sensor is installed, and verify its operation: follow procedures and complete the "Laser Interlock Checklist."
- Check that all operators inside laser enclosure are wearing authorized eye protection.
- Turn on AC power, use key to enable power supply.
- Use local control to energize laser to needed intensity

Additional safety steps for all lid-open operations

[*] These individuals are listed in the EEMC Laser SBSM SOP as "Qualified Laser Operators"

- Enable Infra-Red Interlock Mode.
- Ensure there are no mirrors or sharply reflective surfaces anywhere inside the primary box, other than those rigidly attached to the optical bench.
- Ensure that any temporary beam stops to be employed are diffusely reflective or absorptive.
- Set and keep the laser output intensity as low as possible during all alignment procedures.
- Do not leave the curtained area at any time while the lid is open.
- Disable Infra-Red Interlock Mode upon completion of alignment and maintenance operation.

Operator's name (print): _____ date: _____

Signature: _____

Procedure checklist to verify the operation

of the EEMC Laser interlock system

(These procedures may be performed only by authorized
and properly trained laser operators.[*]
The lid of the primary box will be open during some steps.)

- Sign out the laser power supply key from the cabinet in the STAR trailer.
- Check that the removable access ladder is in place and available.
- Close the manual shutter on the laser head.
- Close the lid to the primary laser box.
- Turn on AC power, use key to enable the power supply.
- Set flashlamp voltage to zero.
- Put on authorized eye protection .
- Close the manual shutter on the laser head.

Testing the primary box interlock:

- Disable Infra-Red Interlock Mode.
- Close the lid to the primary laser box.
- Push the “stand-by” button; verify that laser is ready to fire (stand-by light remains on after 7-second warning beep).

- Open the box lid; verify that laser control reverts to “stop” mode.
- Verify that laser cannot be returned to “stand-by” mode with lid open.
- Close box lid; verify that laser can now be returned to “stand-by” mode.

Testing the infra-red beam sensor interlock:

- Enable Infra-Red Interlock Mode.
- Check that sensor system is installed and receiving AC power.
- Remove any interruptions to the IR beam (red light should go off).
- Push the “stand-by” button; verify that laser is ready to fire (stand-by light remains on after 7-second warning beep).
- Interrupt the IR beam; verify that laser control reverts to “stop” mode.
- Remove interruption; verify that laser can now be returned to “stand-by” mode.
- Disable Infra-Red Interlock Mode.

Operator’s name (print): _____ date: _____

Signature: _____

[*] These individuals are listed in the EEMC Laser SBSM SOP as “Qualified Laser Operators”

Procedure checklist for standard operation **of the EEMC Laser**

(Only authorized and properly trained laser operators[*] may perform these operations)

- — Sign out the laser power supply key from the cabinet in the STAR trailer.
- — Check that the removable access ladder is in place and available.
- — Inspect primary, 1st-, and 2nd-level splitter boxes to ensure that no interconnecting fibers have been disconnected or removed.
- — Ensure that no unauthorized persons are within the curtained enclosure.
- — Check that the manual shutter is open on the laser head.
- — Ensure that the lid of the primary laser box is closed and latched.
- — Verify that operation of the primary box lid interlock has been checked within the previous six months.
- — Disable Infra-Red Interlock Mode
- — Turn on AC power, use key to enable power supply.
- — Use remote or local control to energize laser to needed intensity.

Operator's name (print): _____ date: _____

Signature: _____

[*] These individuals are listed in the EEMC Laser SBSM SOP as "Qualified Laser Operators"